Research on Building Education and Workforce Capacity in Systems Engineering

Interim Technical Report SERC-2012-TR-019-1

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EXECUTIVE SUMMARY

Research on Building Workforce Capacity in Systems Engineering (referred to as RT-19A, SE capstone project, or capstone course throughout) is conducting research to measure the success of student projects in systems engineering at ten main institutions of higher education (IHEs) and five partner schools. Since September 2011, students at the IHEs have engaged in the dual task of designing physical prototypes in multidisciplinary teams and investigating systems engineering competencies, methods, concepts and DoD problem areas. Fifty-two reported faculty are supporting student learning of select systems engineering competencies derived from the SPRDE-SE/PSE model through lectures, take-home and in-class reading assignments on engineering concepts, teamwork exercises, formative and summative assessments, guest presentations, and hands-on prototype development. Mentorships, an integral part of the year-long research effort, have provided students with ongoing technical expertise, project feedback, and opportunities to interact with industry and DoD engineering professionals as well as external faculty.

Distinguishing features of this year's effort include:

- Introduction of a new problem area, Assistive Technologies for Wounded Warriors.
- Systems Engineering content knowledge delivered through a combination of lecture and hands-on work in DoD problem areas beginning in the fall semester.
- Faculty selection of specific systems engineering competencies as course foci.
- Increased utilization of digital tools for distance communication between students' virtual teams and with mentors.
- Addition of partner universities who are developing various forms of collaboration with their partners, including remote development of prototype subsystems.

Expeditionary Assistance Kits and Immersive Training Technologies were the two problem areas chosen by the greatest number of participating schools (6 schools for both areas), followed by low-cost, low-power computing as the second most frequently chosen problem area. Two universities researched the new problem area, added this year (Assistive Technologies for Wounded Warriors), and partnered on the development of a prototype to relieve phantom limb pain. PIs at schools that returned surveys reported student interest (38.5%) and faculty research interest (30.8%) as the top two reasons for selecting a particular problem area.

Nine institutions that had participated in RT-19 returned this year for RT-19A. Faculty at five institutions reported making minor changes to their courses. Faculty at two schools reported making major changes, including emphasizing general systems engineering concepts and models and lessening instruction on software engineering principles. The remaining six PIs designed entirely new capstone courses.

DoD problem areas and student prototypes

Faculty reported that the following student prototypes (organized by problem area in the list below) were in development:

Problem Area 1 – Low-cost, low-power computing

- Portable UVA to be launched by soldier to reconnoiter hostile environment by air
- Small-scale, low-voltage battery management and charging system
- Small sailing robots that can operate autonomously in navigation and communicate with each other for coordinated operations
- Small-scale model of the power plant and vehicle providing proof of concept

Problem Area 2 – Expeditionary Assistance Kits

- Prepositioned Expeditionary Assistance Kit
- Fully functional, independently powered (e.g., renewable power source) water purification system capable of supporting at least 80 people from multiple water sources
- Power sub-system in partnership with Naval Academy
- Shipboard wastewater treatment system development for Coast Guard cutters (includes development of membrane-bioreactor for treating shipboard gray water and pollutant removal)
- Natural gas engine conversion

Problem Area 3 – Expeditionary Housing

- Green housing

Problem Area 4 – Immersive Training Environments

- Cockpit/Crew Station of the Future (2035) used as a simulator to train pilots
- Immersive training vests with position reporting and vibrators
- Interactive, immersive training environment with human gesture tracking and facial emotion capture
- Distributed systems assurance processes and methods

Problem Area 5 –Assistive technologies for wounded warriors

- Immersive technology to alleviate phantom limb pain

Faculty

According to the PI interim survey, 52 faculty members in nine areas of engineering, including mechanical, systems, electrical, computer science, software, civil, aeronautical, ocean and industrial engineering, contributed their time and expertise to RT-19A effort. At thirteen institutions, PIs reported that all faculty assumed multiple and often overlapping roles in RT-19A--as curriculum developers, subject matter experts, lecturers, team advisors, liaisons to SERC and to DoD/industry mentors, and as mentors to students on an individual, disciplinary-specific basis.

Many aspects of capstone course design and implementation were shared by PIs. At nine schools, instruction in the Fall semester was delivered as a combination of lecture and design-based work on the DoD problem area. Faculty at four schools reported working solely on the DoD problem. All institutions implemented presentations and design reviews as formative and summative assessments--one of the promising practices of effective systems engineering teaching and learning reported by RT-19 sponsors. At 7 schools, capstone courses were required of undergraduate students. Faculty reported that face-to-face student conversation was the

most successful recruitment strategy, followed by discussion with auxiliary departmental faculty or advisors who then informed students of the capstone course offering.

Students

A total of 285 students answered the RT-19A baseline survey, slightly less than the 294 students who responded last year. The gender of the student population was similar to last year, with over three-quarters reporting as male, less than 20% reporting as female, and the rest selecting not to report gender. Two-thirds of the students were white, with the remainder Asian (14%); Black or African American (9%); Hispanic/Latino (4%), Hawaiian, Alaska Native or American Indian (< 3%); and 5% not reporting ethnicity. Students represented a wide range of disciplines, with systems engineering and mechanical engineering as the two majors with the greatest number of students. Fifty-five percent of the students who responded were undergraduates, 38% were graduate students, and 7% were postgraduates. All institutions except for two (Auburn and Naval Postgraduate School) reported that their classes were comprised of undergraduate students. The population at NPS was entirely graduate students, while only one school, Auburn, reported that a mixed student population of undergraduate and graduate students worked together on the capstone project.

Despite the high percentage of students who reported that they were systems engineering majors, 59% of the students who responded to the survey had no systems engineering experience. Of the students who did have experience, 49% had had coursework in systems engineering and 20% had had full-time employment. Thirty percent of students reported high interest in systems engineering careers, 20% reported moderate interest, and 8% reported no interest. Seventeen percent of students reported high interest in working for the government as a systems engineer.

Sixty-nine percent of the student teams were inter/multidisciplinary, and team sizes ranged from 2 to 14 with an average of 6 students per single team. Four PIs reported that students in their classrooms had no experience working in multidisciplinary teams, while the other 9 PIs reported varying interdisciplinary team experience.

Mentorships

All schools reported working with a DoD mentor, an industry mentor, an external faculty mentor, or several of these. The interaction of this year's mentors with students, as reported by the surveyed PIs, aligned with two of RT-19's promising practices, "Regular, direct involvement of mentors with student project teams-- e.g., significant meetings twice monthly with 'on-call' consultations between meetings" and "Structured design reviews with DoD and industry mentors serving as reviewers." DoD mentors at seven schools communicated regularly with the students, providing them with initial requirements definition, ongoing technical advice and feedback during design reviews. Students at the Coast Guard Academy also visited the worksite of their DoD mentor.

A major difference between this year and last was the inclusion of many more industry mentors. At eleven schools, students collaborated with professional engineers at the following companies, government agencies, and research centers: American Electric Vehicles, Aqua Sun, BAE Systems, The Boeing Company, Buro Happold Engineers, Frontier Technology, Lockheed Martin Aeronautics Company, Northrup-Grumman, and Potomac Training Corporation, NASA,

Missile Defense Agency, US Army Aviation and Missile Command, and Auburn University Huntsville Research Center.

Industry mentors worked with students at all IHEs surveyed except two partner schools as technical advisors, clients, subject matter experts and reviewers. Students and mentors communicated at least several times a semester by email, telephone, teleconference, videoconference and exchanged work through online file-sharing websites. When time and opportunity allowed, industry mentors paid visits to 7 schools. At two schools, University of Virginia and Sweet Briar College, students visited industry worksites.

Systems engineering career interest

Another suggestion for this year was that PIs incorporate explicit discussion of systems engineering careers into the capstone courses. Nine out of 13 PIs who responded to the survey stated that they had included or would include discussion of careers in the context of informal classroom discussion (39%) or through interaction with a guest speaker or mentor (30%).

Challenges and successes

PIs reported that students encountered many of the same challenges and successes at the midpoint of their yearlong capstone. The areas of greatest challenge included teaching students complex systems engineering concepts and content knowledge in a compressed timeframe and facilitating interdisciplinary and distance communication between team members. The areas with the greatest success were communication with clients and mentors, student interest in "real-life problems," and hands-on practice with systems engineering content knowledge, particularly in the competencies of Communication and Requirements definition.

In addition, the impact of RT-19 and RT-19A as reported by faculty extended beyond the classroom. For example, students at two universities who had participated in RT-19 were helpful in recruiting students to RT-19A.

Dissemination

Four PIs reported that they planned to disseminate results of RT-19A through student conferences and competitions. Three PIs reported that they had submitted papers to academic journals.

BACKGROUND

Continuing from RT-19, the goal of RT-19A is learn how students' competencies in SE are affected by their capstone experiences. The Systems Planning, Research Development, and Engineering Systems Engineering and Program Systems Engineer (SPRDE-SE/PSE) competency model continues to be used as the standard for SE knowledge and skill.

SPRDE-SE/PSE Competency Model

Analytical (13)	1. Technical Basis for Cost
	2. Modeling and Simulation
	3. Safety Assurance
	4. Stakeholder Requirements Definition (Requirements Development)
	5. Requirements Analysis (Logical Analysis)
	6. Architectural Design (Design Solution)
	7. Implementation
	8. Integration
	9. Verification
	10. Validation
	11. Transition
	12. System Assurance
	13. Reliability, Availability, and Maintainability
Technical Management (12)	14. Decision Analysis
	15. Technical Planning
	16. Technical Assessment
	17. Configuration Management
	18. Requirements Management
	19. Risk management
	20. Technical Data Management
	21. Interface Management
	22. Software Engineering
	23. Acquisition
	24. Systems Engineering Leadership
	25. System of Systems
Professional (4)	26. Communications
	27. Problem Solving
	28. Strategic Thinking
	29. Professional Ethics

Since one goal of RT-19A is to understand how best to increase the number of schools offering systems engineering capstone courses, participants from RT-19 were encouraged to partner with non-participants in RT-19A. As a result, 6 new schools are participating, partnering with 7 returning SERC schools and 4 service academies. The 17 universities are required to address one

or more of five DoD problem areas and to produce an actual product, prototype, or other artifact to demonstrate their learning. In addition, they were asked to incorporate as many of the 9 Promising Practices as feasible in their courses.

SE Capstone RT 19 Promising Practices

1. Fall semester tools/techniques/approaches SE theory course, followed by spring semester design project course. Fall course should present balance of "traditional" SE approaches with automated tools/ models/ simulation techniques.

2. Cross-disciplinary student teams.

3. Regular, direct involvement of mentors with student project teams-- e.g., significant meetings twice monthly with "on-call" consultations between meetings.

4. Established relationships with nearby DoD commands and facilities.

5. Creative use of mentors from defense prime contractors.

6. Structured design reviews with DoD and industry mentors serving as reviewers.

7. Use of SE Ph.D. candidates as project advisors.

8. Creative imposition of technical, budget, and schedule constraints by faculty to model "real world."

9. For civilian institutions that have on-campus ROTC units, established relationships with ROTC units for requirements analysis, use case testing, and solution viability.

DoD Problem Areas

1. Low-cost, low-power computers leveraging open-source technologies and advanced security to support sustainable, secure collaboration;
   Portable, renewable power generation, storage, and distribution to support sustained operations in austere environments and reduce dependency on carbon-based energy sources;
   Portable, low-power water purification;
2. An expeditionary assistance kit around low-cost, efficient, and sustainable prototypes such as solar cookers, small and transportable shelters, deployable information and communication technologies, water purifiers, and renewable energies. These materials would be packaged in mission-specific HA/DR kits for partner nation use;
3. Develop modular, scalable, expeditionary housing systems that possess "green" electric power and water generation, waste and wastewater disposal, hygiene, and food service capabilities. Systems should be designed to blend in to natural/native surroundings and with minimal footprint;
4. Continued investigation and exploration into the realm of the possible with respect to "Immersive" training technologies. Objective is to flood the training audience environment with the same STIMULI that one would experience during actual mission execution. Where possible full sensory overload is desired much the same as experienced in combat. Specific S&T areas for development
   - *Virtual Human*. Successful modeling of emotions, speech patterns, cultural behaviors, dialogue and gestures.
   - *Universal Language Mode*l. The ability for trainees to seamlessly converse with the Virtual Human.
   - *Virtual Character Grab Controls*. The ability for exercise controllers to assume control of virtual characters.
   - *Automated Programming*. Cognitive learning models and the ability for exercise controllers to adjust virtual/live simulations.
   - *Low Cost wireless personnel sensors*.
   - *Sensors* (i.e., lightweight vests) that facilitate physical stimuli (i.e., wounds, shots) to trainees.
5. Assistive technologies for wounded warriors, including but not limited to application of haptic research, augmented reality, research from traumatic brain injury, bio-medical advances, hybrid assistive approaches (e.g., human- machine interfaces) and other leading- edge technologies to facilitate rehabilitation and contribute positively to wounded warrior quality of life.

The program is being implemented in three sequential phases over an 18-month period.

During Phase 1/Planning and Startup (April 1, 2011-June 30, 2011), the research team, with participation from the sponsor agency:

- Developed the requirements and specifications, timeline, and funding limits for the SE Capstone Projects
- Developed the research design and project evaluation plan
- Developed and issued the request for proposals and selection process (an independent review team and rubric) for selecting participating institutions
- Concluded with the selection of seven civilian universities and four service academies with SE programs that would participate in the project

During Phase 2/Development and Implementation (July 1, 2011-June 30, 2012), the Capstone Team Members will: recruit student participants; develop and organize course materials; coordinate and engage mentors and clients; plan assessments; and conduct courses; participate in recommended student competitions and conferences (Spring 2012); and submit an interim report (January 2012) and a final report (June 2012). Some variation in this schedule is likely based on the specific calendar for classes at each institution.

Each Capstone Team Member will administer two types of assessments to their students:

- Customized pre-/post assessments that are targeted to their own course learning objectives. These assessments would typically be developed by the course instructors and relate to the specific course content presented. These assessments may range from multiple choice response tests to a performance-based assessment (which may be assessed using a scoring rubric), to other types of authentic assessments.
- A common student assessment, developed by the research team and administered in survey format at the beginning and end of each course that will:
    - gauge changes in student involvement in, and understanding of, the SE design process, including the requirements, design review, and testing phases; the system trade-offs; and the nature and type of client interactions
    - gauge changes in student interest in SE study and SE careers, including DoD careers
    - collect demographics, including majors, whether graduate or undergraduate, prior experience with SE, etc. on participating students

Each Capstone Team Leader will be asked to respond to a survey that asks details about the scaling process, the challenges to sustainability, and the reasons behind the success (or lack of it) on the student projects.

In addition to developing and administering student- and faculty-level instruments, the research team will conduct detailed case studies of four of the SERC partner universities. Case studies will describe the models, approaches, and conditions that universities have employed that have led to successful student projects, indicators of sustainability and institutionalization, which provide specific examples of best practices will be detailed. A further analysis, a compilation of ineffective practices and unresolved challenges, will also be detailed. These case studies of

effective programs and compilation of ineffective practices will lead to the development of a tool or methodology that could be used subsequently to look for the conditions that need to be in place if a project is likely to be successful, thus providing guidelines for future DoD investments in SE projects.

During Phase 3/Analysis, Recommendations & Dissemination (July 1, 2012 – September 30, 2012), the research team will analyze the results from all participating Capstone institutions and integrate them into a single set of findings to the sponsor about the effectiveness of the programs using a variety of metrics:

- Student learning of SE skills and competencies
- Success of student projects
- Effectiveness of course structure, materials, and external inputs (mentors and clients)
- Institutional infrastructure and institutionalization
- Scale up

To facilitate that analysis and recommendations, the SERC research team will host a workshop for all Capstone Team Members, the government sponsors, and other relevant, invited guests in July 2012. At that workshop, the results of the individual Capstone Team Members will be presented. The attendees will work under the guidance of the PI to analyze those results and prepare draft recommendations.

ANALYSIS OF FACULTY REPORTS

This section of the report will summarize progress as of January 2012. It is based on an analysis of the participating institution's responses to an interim survey and of a student baseline (pre-course) survey. A final section includes an executive summary.

Reporting Institutions

A total of 13 institutions returned the interim survey. These included nine of the ten main institutions and four of the six partner institutions. Five main schools had recruited partners—one had recruited two while the others had recruited one each. All of the main institutions had participated in RT19 last year. Those that did not respond to the survey are highlighted in gray:

RT-19A Main Institution	Partner Institution
Air Force Academy	
Auburn University	Tuskegee University[1]
Coast Guard Academy	Connecticut College
	University of Rhode Island
Missouri University of Science & Technology	
Military Academy	
Naval Academy	Smith College
Naval Postgraduate School	
Southern Methodist University	University of Hawaii Manoa
Stevens Institute of Technology	
University of Virginia	Sweet Briar College

Partner Institutions

Five schools recruited partner institutions. Four recruited one institution and one (USCGA) recruited two, so there was a total of six partner schools. In two cases (SMU, USNA), one faculty member was participating from the partner institution; in three cases (Auburn, USCGA, UVA), there were two.

Faculty from the partner institutions were playing a number of different roles, including creating course materials and managing student teams. Students from the University of Hawaii were playing a particular role in the SE process:

> SMU (partnering with University of Hawaii): (1) Four students at the ITM department in University of Hawaii (UH) play the role of independent system assurance personnel.

[1] Since Tuskegee did not have students participating, it was not asked to respond to the interim survey. However, the PI from Auburn did responses to the partnership questions on his survey.

They formed two system assurance teams to work with two SMU project development teams to review their project artifact deliverables and make the system assurance plan for the SMU teams based on the artifact review results. (2) The faculty PI at the University of Hawaii (UH) added the course materials to cover system assurance in the UH senior design courses. He also recruited students to form the two system assurance teams at UH and advise, monitor and control the system assurance activities. He also periodically met with the SMU PI and attended the client meeting via Skype in October, 2011 to discuss the project plan.

But in the other three cases, the students in the partner institutions were considered partners on the project, acting as subteams:

USCGA (partnering with University of Rhode Island and Connecticut College): Each institution is creating a parallel solution that complements solutions from other institutions. We are creating complementary designs that do not have another institution's design solution in the critical path. This approach allows each institution to create a partial design that can be fitted with a complementary design from another institution to complete the final design. URI is focusing on autonomous systems that can communicate and use vision to navigate to a target. Connecticut College is focusing on autonomous systems that can collaborate on a goal. USCGA is focusing on autonomous systems that can maintain station and formation using electronic navigation systems.

UVA (partnering with Sweet Briar College): The faculty members are co-advisers to the team: Gerling and Pierce for one team, Brinkman and Louis for the other. The students from SBC are ‘regular’ team members.

USNA (partnering with Smith College): The students from the partner institution are serving as a fully integrated sub-team for one of the project teams. They will create a working prototype of their part, which will be integrated into the overall system in the spring. The faculty member from the partner institution serves as team advisor and subject-matter expert for the students from that institution. In addition, the faculty members from both institutions talk frequently to share ideas, compare progress and clarify any issues.

Auburn recruited faculty only, so their relationship was different:

Auburn (partnering with Tuskegee—faculty only): The objectives of this project are to have faculty members from Tuskegee University observe and advise the Auburn University faculty team on (1) the quality of the systems engineering course, and (2) how best to position the course material for use by another university. Specifically, Tuskegee University’s responsibilities include the following subtasks: (1) Verify that the course sequence achieves stated education objectives: • Attend course lectures or watch the lecture videos. • Participate in teleconferences with the project’s Industrial Advisory Board. • Review student team project conceptual designs and assist in the down-selection process. • Participate in status report meetings. Such meetings will be held in person or via teleconference. • Take part in a course postmortem session at the end of each semester. • Assess how well stated course objectives were met. Deliverables include: • Verbal recommendations at status meetings, Industrial Advisory Board meetings, and semester postmortem sessions. • Written report recommending, with justification, which fall semester student projects should be implemented in the

spring semester. (2) Provide recommendations on how to position the course material for use by another university: • Assist in setting up a visit of the AU instructional team at Tuskegee University. The objective of the visit is to get TU students interested in systems engineering. • Recommend how to package the course in a turnkey fashion for use in a university environment similar to Tuskegee University. Deliverables include: • Facilitation of AU's visit to Tuskegee University. • Written report assessing the degree to which each educational objective was achieved. • Written report recommending how to advertise, package, fund, deliver, support, and assess student performance of AU's systems engineering sequence in a university of Tuskegee University's size and educational composition. The report may address transition of the courses directly to Tuskegee University with the understanding that TU is not obligated to undertake the courses.

We have no specific students from Tuskegee University working with Auburn University; however, we plan to conduct seminars at Tuskegee University to get the students there excited about the systems engineering discipline.

In all cases where there were students, the PIs described the students in the partner institutions as collaborating closely with the students in the home institution. However, as noted above, the division of labor between institutions varied, from dividing the systems engineering process itself to dividing the object being built into a series of subsystems or tasks, each built by a different school. The collaborations were conducted using telephone conferencing, Skype with audio and/or video, email, shared document storage (either Dropbox or GoogleDocs), and (in two cases) in-person visits. Here are the specifics:

SMU: Students from SMU and UH work through email and Skype to complete their team mixing process. Two SMU teams play the role of system developers and two UH teams play the role of independent system assurance. Each SMU development team selected one system assurance team from UH to collaborate with by November 2011. Students held their periodical meetings via Skype and frequently exchange project progress via email. The project artifacts were shared and exchanged between distributed teams through Dropbox.

USCGA: The students divided the bigger project into smaller subsystems and are pursuing the final goal by sharing information. For example, USCGA cadets are designing the water-based vessel and control system for electronic navigation. The URI students are developing a land-based system for using vision to navigate to a target. By combining the two systems, the students will be able to synthesize a system that can navigate to a point on water, maintain station-keeping at that point, and then navigate to a docking station using GPS and DGPS signals to get close, then use vision to complete docking. Connecticut College is providing the software so multiple autonomous vessels can collaborate on tasks.

UVA: Teams were sub-divided, and the SBC students were assigned sub-tasks and treated no differently than the UV students. The teams have weekly video meetings, and several meetings each semester together at one location or the other.

USNA: The students talk via video-conference once per week, in addition to frequent e-mails. The students from Smith College visited the Naval Academy this fall. Some of the

> Naval Academy students will visit Smith College in the early spring, and the Smith College students will return to the Naval Academy in the late spring for final implementation of their design into the overall system.

All the PIs felt that the different modes of communication were effective, but two noted that at least some face-to-face communication really helped move the process along.

Program Structure

Each university organized the structure of its program and the content of its pilot course(s) differently, depending primarily on the existing capstone course structure at the particular institution, the expertise and research interests of the faculty recruited into the effort, the types of students and their research interests, and the mentors available. The key features that differentiated the organizational structure of the programs at the different universities were the following:

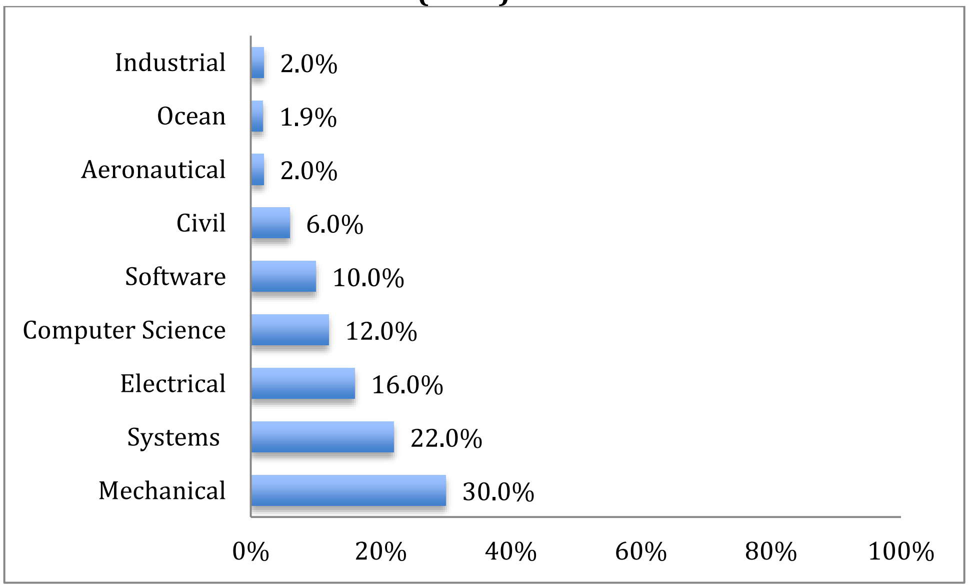
- Faculty: The collaboration of two or more faculty members on course design and implementation.
- Courses: The integration of the SE component into existing courses or the creation of entirely new courses.
- Course sequencing: The implementation of a course sequence that included an introductory course followed by a capstone experience or a capstone experience only.
- Mentors: The presence and level of active and meaningful involvement of DoD, industry and external faculty mentors in a variety of student learning experiences.
- Student population: The involvement of both undergraduates and graduate students as learners or only one of these.

The following sections will discuss these in more detail.

Faculty Involvement

Faculty came from Industrial, Electrical, Civil, Mechanical, Systems, Software, Ocean Engineering, and Computer Science. The highest percentage came from Mechanical Engineering, followed by Systems Engineering. In this graph, percentages represent the total faculty members in the project:

All institutions - By faculty discipline (n=12)[2]



Over half (8 out of 13) of the schools included faculty participants from more than one engineering discipline:

Institution	# of faculty	Faculty by discipline	Faculty roles
Auburn University	3	1 Industrial Engineering 2 Software Engineering	Curriculum designers, lecturers, liaisons with industry mentor
Air Force Academy	N/R	N/R	
Coast Guard Academy	11	2 Civil Engineering 3 Electrical Engineering 6 Mechanical Engineering	Team advisors
Connecticut College	3	3 Computer Science	Team advisor and subject matter expert
Military Academy	4	3 Mechanical Engineering 1 Systems Engineering	Team advisors, subject matter expert and liaison with DoD/industry mentors

[2] One PI did not answer this question

Missouri University of Science and Technology	8	1 Computer Science 2 Electrical Engineering 1 Mechanical Engineering 4 Systems Engineering	Curriculum designers, subject matter experts, and liaisons with guest speakers from SE community
Naval Academy	5	1 Electrical Engineering 3 Mechanical Engineering 1 Ocean Engineering	Curriculum designer, subject matter expert, lecturer, team advisor, liaison with DoD/industry mentors
Smith College	1	1 General Engineering	Curriculum designer, team advisor, and liaison with SERC/Stevens, capstone coordinator
Southern Methodist University	4	2 Computer Science (1 Electrical Engineering) 2 Software Engineering (1 Systems Engineering)	curriculum designers, team advisors, subject matter experts & liaison with DoD/industry mentors
Stevens Institute of Technology	4	1 Civil Engineering 1 Electrical Engineering 1 Mechanical Engineering 1 Systems Engineering	Team advisors
Sweet Briar College	2	1 Aeronautical Engineering 1 Mechanical Engineering	Team advisors
University of Hawaii at Manoa	1	1 Software Engineering	Lecturer, team advisor, and subject matter expert
University of Virginia	6	6 Systems Engineering	4 are lecturers, team advisors, and subject matter experts. 2 serve as curriculum designers, project reviewers and liaisons with DoD/industry)mentors
TOTAL	52		

RT19A Courses and Student Demographics

Ten schools offered only one RT-19A capstone course; the rest offered two courses.
At nine schools, instruction in the Fall semester was delivered as a combination of lecture and design-based work on the DoD problem. Four schools reported working solely on the DoD problem.

Below is a table of undergraduate and graduate students by institution. More detail on overall student demographics, including student status, year, gender, ethnicity, engineering background and career interest, is located in the Analysis of Student Participants section of this report. Graduate students were recruited as mentors, team advisors or project leaders at six schools and were hired as teaching assistants at three.

Institution	Course name	Number of sections	Number of students (U = Undergraduate, G= Graduate, P= Postgraduate), Fall semester	Expected number Spring semester[3]
Auburn University	Systems Engineering using Secure Open Source Technology I	1	7 U 22 G	14
Air Force Academy	Senior Capstone Design or Independent Study (offered for all departments)	1	5 U	5
Coast Guard Academy	Design Project Management (Mechanical Engineers) or Capstone Project/EE1 (for Electrical Engineers)	2	42 U	50
Connecticut College	Research Seminar	1	2 U	12
Military Academy	Systems Engineering/ Engineering Management	1	4 U	4

[3] In some schools, students who take the Fall semester course do not work on a DoD problem area. The expected number of the Spring semester is specifically those working on a DoD area.

	Capstone			
Missouri University of Science and Technology	Systems Engineering and Analysis I Systems Engineering and Analysis II	1 1	1 U 47 G	46
Naval Academy	Engineering Systems Design Mechanics of Materials	2 1	38 U	44
Smith College	Design Clinic	1	4 U	4
Southern Methodist University	Software Engineering Principles Senior Design I	1 1	46 U	8
Stevens Institute of Technology	X 423 Senior Design (where X refers to the various disciplines involved, electrical, mechanical, civil, environmental)	1	24 U	24
Sweet Briar College	Senior Capstone Design	1	4 U	2
University of Hawaii at Manoa	Introduction to Systems Application Programming	1	24 U	15
University of Virginia	Systems Design I	1	18 U	16
TOTALS			288	244 (predicted students in spring. Figure does not include NPS)

Changes Made by Returning Schools

PIs from the nine returning schools[4] were asked about the changes that they had made as a result of their RT19 experience. Five of the nine said they were offering the same course in the

[4] Naval Postgraduate School was also a returning school; however, it is not included in this section because there was no RT-19A interim survey submitted as of January 2012.

fall semester that they had offered last year, but two (Auburn, University of Virginia) reported that they had made major changes and two (SMU, Naval Academy) said they had created an entirely new course. One of those who had created an entirely new course had been a PI last year (SMU), while the other had taken over for last year's PI (Naval Academy).

One of the schools that reported major changes (Auburn) and one that reported creating an entirely new course (SMU) did so in order to overcome a perceived issue with RT19, which was that the project had been too narrowly conceived and had therefore not sufficiently appealed to students in more than one department or track. For Auburn, the narrow focus had had several additional ramifications that their changes also sought to address:

> Auburn: Our first RT19A course was similar to our RT19 effort, but with major changes that addressed shortfalls gleaned from last year. The most important insights we learned from RT19 were (1) our approach to systems engineering was perceived as being too software-centric; (2) we didn't introduce security aspects early enough in the curriculum; (3) we didn't convey well enough what "open source" means and how to assess benefits and liabilities of open source technologies; and (4) we were disappointed that there was little cross-pollination of systems engineering concepts among student teams in the second semester due to the vastly different prototypes built by each team.
>
> To mitigate these issues in RT19A, we modified our approach. We retained the same educational outcome -- that of providing the students with a broad-brush exposure to systems engineering concepts -- but we retooled the course by (1) refocusing in-class time on systems (versus software) concepts ; (2) beefing up the security and open source content; (3) introducing in the first semester a systems scenario to be addressed in the subsequent semester.
>
> We addressed the first issue by making the time we spent in the classroom to be as lean as possible. We did this by requiring the students to read the textbook and outside readings on their own time and use class periods to discuss concepts in the context of implementing secure systems using open source technology. Despite a majority of the students in the class having a software engineering background and trying to frame the in-class discussion in software terms, we steered the conversation by explicitly asked them to consider issues outside the software domain. Our aim was to encourage students with an industrial engineering background to participate by providing an extra dimension beyond software.
>
> We addressed the second issue by making a conscious effort to note that security and open source technology are not relegated exclusively to the software domain, but must pervade all aspects of the systems lifecycle, including design of both physical and logical components; manufacturing; deployment; operations; and eventual transition to newer and more advanced systems. We emphasized the ambiguity of the term "open source" by presenting a spectrum of ideas, processes, and solutions using proprietary technology at one end and technology available through the public domain at the extreme opposite end. Throughout, we continually asked the questions, "What are the security risks to the proposed system design?", "How does the proposed system mitigate the risks?", "How can the risk mitigation features be verified and validated?" As part of this discussion, we introduced DIACAP (Defense Information Assurance

Certification Assessment Process).

The third issue was addressed by asking student teams to develop a conceptual design for a portable unmanned aerial vehicle that can be launched by a soldier for the purpose of reconnoitering a hostile environment from the air. The teams were charged with incorporating as much open source technology as possible into their designs as well as illustrating how secure their systems are. The teams were informed that one or possibly two designs will be chosen for implementation in the subsequent semester. Our hope was that this would motivate the teams to do a careful and complete design. We are currently in the process of down-selecting the seven conceptual designs. This was a significant departure from last year; we didn't start the project until the second semester and allowed the student teams to propose their own needs statement. Our objectives this year were to provide a concrete forum for demonstrating concepts discussed throughout the semester, to set up a competitive environment, and to establish a means by which teams could be assessed relative to each other.

SMU: We have opened an independent new course entitled as CSE4351 (Senior Design I) which is taught in parallel with our old course CSE4345 (Software Engineering Principles) in Fall 2011 semester. However, there are no major changes in the theme and objectives of the course. Because we teach the new course concurrently with our old version of Senior Design I course CSE 4345 which still follows the previous year's curriculum and course materials, we put much more weight on project discussion and team meetings with faculty in the new course curriculum while keeping the lectures in the CSE4345. [The majority] of the Senior Design I students have taken or are taking the CSE4345 concurrently with CSE4351.

The reason we created the new CSE 4351 Senior Design I course in Fall 2011 is to unify the Senior Design course curriculums of Computer Science and Computer Engineering tracks. Prior to Fall 2011, the Senior Design course curriculums of Computer Science and Computer Engineering tracks were different in that Computer Science track students took CSE4345 (Software Engineering Principles) in the Fall semester and CSE 4346 (Senior Design) in the Spring semester together with Computer Engineering track students. Thus Computer Science (CS) track has a senior design curriculum spanning one year while Computer Engineering (CE) track only has a one semester senior design course. Since Fall 2011, we have unified the senior design course curriculums for both Computer Science and Computer Engineering tracks by creating the new course Senior Design I in Fall semester and Senior Design II in Spring semester for both CS and CE tracks.

In addition, based on the lessons learned from last year, undergraduate students were mostly confused by the general and abstract concepts, terms and principles introduced in the joint system engineering lectures. This year we tried to redesign the system engineering joint lecture to address more basic, tangible, and easy-to-understand SE topics which may directly impact the skill set needed for interdisciplinary senior design project development.

The other school that reported major changes was UVA. Although the PI did not include many details in the pre-survey, the original proposal described some of these changes:

UVA: (1) We restructured the course accounting for feedback from last year's program (as covered in proposal), and (2) We added the second school, Sweet Briar College, which added a new dimension of teamwork and team coordination.

Freshman through Seniors: We are incorporating, through UVA's unique Technology Leadership Program (TLP), a conduit to involve freshman, sophomore, and junior students in electrical and systems engineering in the capstone projects.

Mentor Program: Mr. Bill Campbell, who was instrumental in supporting our capstone projects last year, has agreed to be a lead-mentor and play a more significant role in the proposed program.

Systems Integration: The proposed project, by incorporating multiple disciplines and two locations (laboratories at UVA and Sweet Briar), will expose student to these aspects of engineering and require that engineering management and integration activities are effectively conducted.

Social Media: Given the feature of two schools involved, we will use distance collaboration and social media tools to maintain interactions across the students, faculty, clients, mentors, etc.

Other New and Continued Features: Based on aspects that were effective last year, RT - 19 best practices, and conversations with other schools, we will a) involve students from our ROTC units (primarily for testing and user feedback), b) continue to have graduate students assistants for each project, c) send representatives from both teams to the West point Capstone Competition and SIEDS, and d) continue and update our SE lecture series.

The Naval Academy created a new course, but this was done not to rectify problems from RT19 but in order to bring in more students:

Naval Academy: Last year's implementation of RT-19 was on a relatively small scale, with two 4-person capstone engineering design projects (electrical engineering and mechanical engineering majors) as the main focus of the involvement. This year, building off the successes of last year, we created an entirely new capstone systems engineering design course for USNA students in the General Engineering major. In the past, this major did not include a capstone design experience. However, the focus of the major lends itself very well to the Systems Engineering process, and RT-19A provided the impetus to create the courses (one course in the fall with a follow-on course in the spring) to support a capstone design experience with a Systems Engineering focus. This year, all 28 General Engineering students at USNA will complete capstone design projects as part of these courses. Now that the courses have been developed, the intent is to continue offering them each year hereafter. The matrix of required courses is being changed so that Engineering Systems Design I and II are mandatory courses for General Engineering majors.

Although Stevens reported only minor changes, their description suggests that they did a considerable amount of reorganization:

Stevens: A refocus on the data acquisition from prototypes and subsequent system level modeling and analysis to validate last year's concepts. Expanding project scope to include post-disaster relief. Established an organization change to include a systems level leadership team. Formalized the content delivery in additional lectures.

Finally, Coast Guard Academy and UVA reported small additional changes:

Coast Guard Academy: We now provide our students with the syllabus for the entire academic year with all key dates listed.

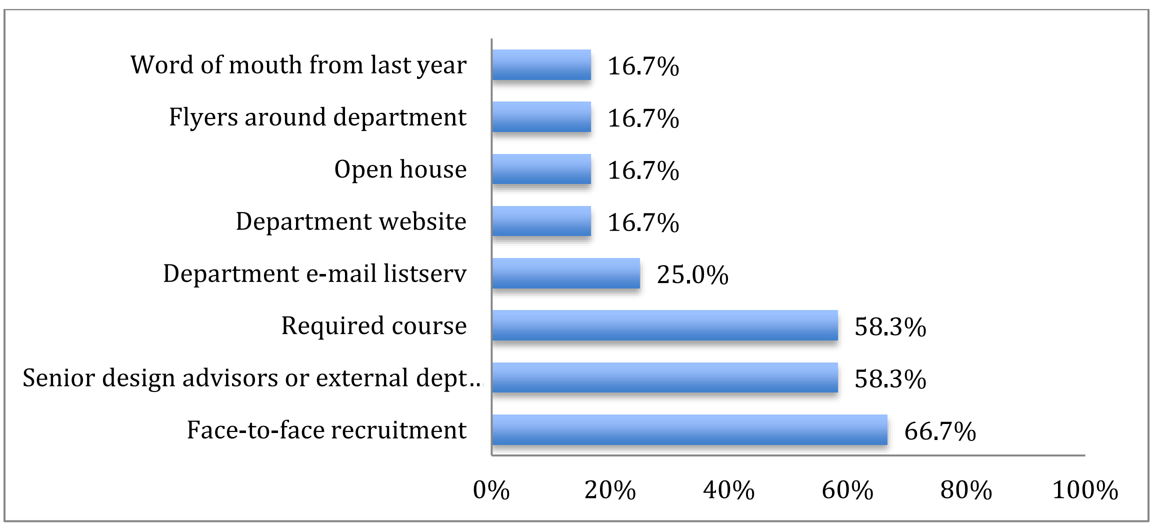
UVA: Increased industry reviews to one per semester per team (as opposed to one per year), given outstanding feedback as to the value.

Recruitment Methods

Faculty employed multiple strategies for recruitment, with recruiting students face-to-face cited as the most effective strategy.

At Stevens Institute of Technology and Auburn University, two participants of RT-19, word of mouth from students in the previous year impacted recruitment positively. PI conversations with faculty from other departments (University of Virginia) and with senior design faculty (Southern Methodist University) also increased student recruitment. The graph below shows the methods most frequently used, with many institutions using more than one:

Student recruitment methods, n=12[5]

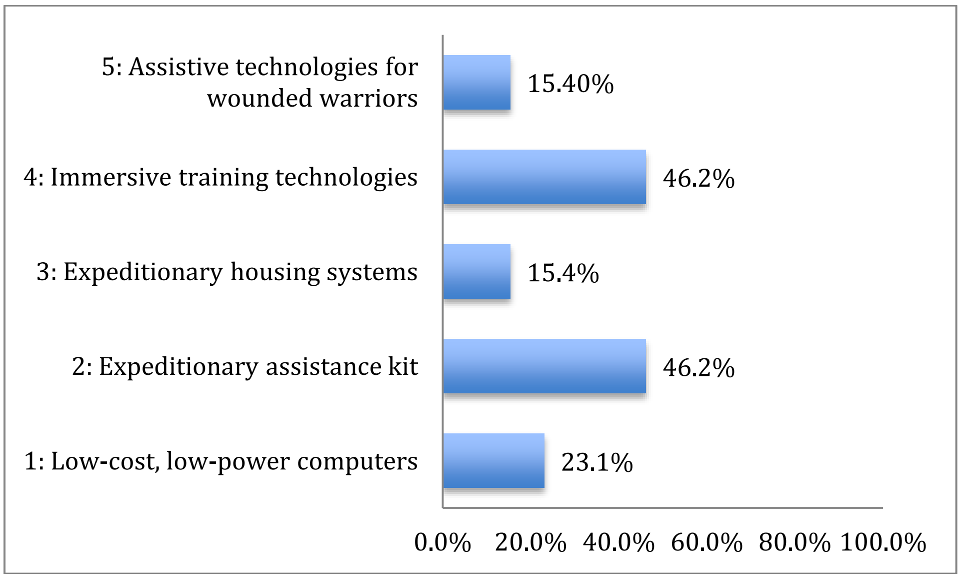


[5] One PI did not to answer this question.

DoD Problem Areas Addressed

Each of the universities, including main institutions and partner institutions, chose one or more of five problem areas based on existing faculty expertise, student interest, and other factors such as extending last year's problem area. Three institutions addressed multiple DoD problem areas. Problem Areas 2 and 4 were most frequently chosen, while Problem Area 3 and 5 were least represented. The following table shows percentage of institutions choosing each area:

DoD Problem Areas addressed



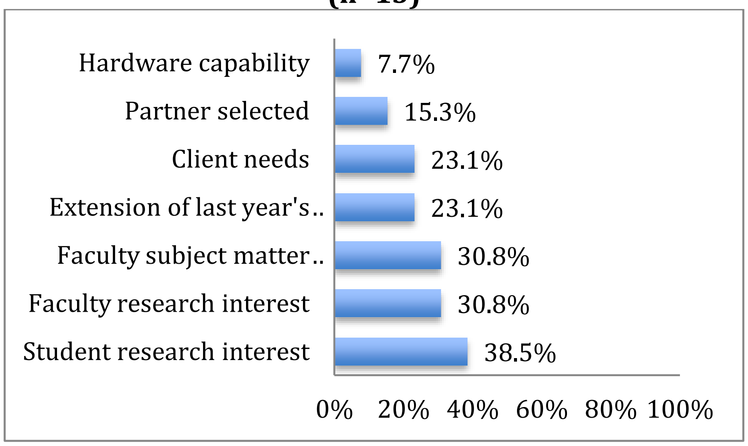
The following table shows problem areas by institution:

Auburn University	1
Air Force Academy	2
Coast Guard Academy	1,2,3
Connecticut College	1,2
Military Academy	4
Missouri University of Science and Technology	4
Naval Academy	2
Smith College	2
Southern Methodist University	4
Stevens Institute of Technology	3
Sweet Briar College	4,5

University of Hawaii at Manoa	4
University of Virginia	2,4,5

The PIs identified student interest, faculty interest, and faculty subject matter expertise as the top reasons for selecting a problem area. Two schools reported that they selected the problem area based on client needs (Military Academy, Southern Methodist University.) At two partner institutions (Connecticut College, University of Hawaii Manoa), the sponsoring university decided upon the problem area. In the graph below, PIs could identify one or more reasons for selecting a given problem area.

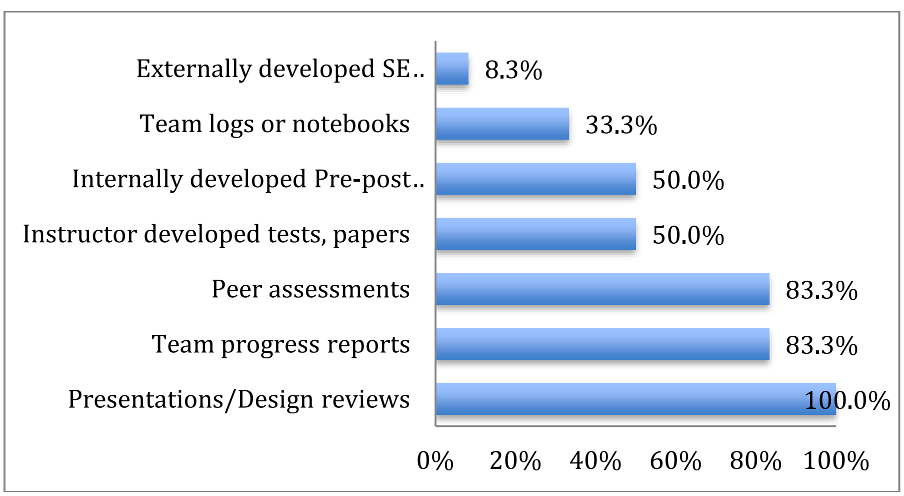
All institutions – By problem area selection (n=13)



Types of Assessment

The chart below shows types of assessments used, with some institutions using one or more types of assessment:

All institutions – by Systems Engineering assessment type



Student Prototypes

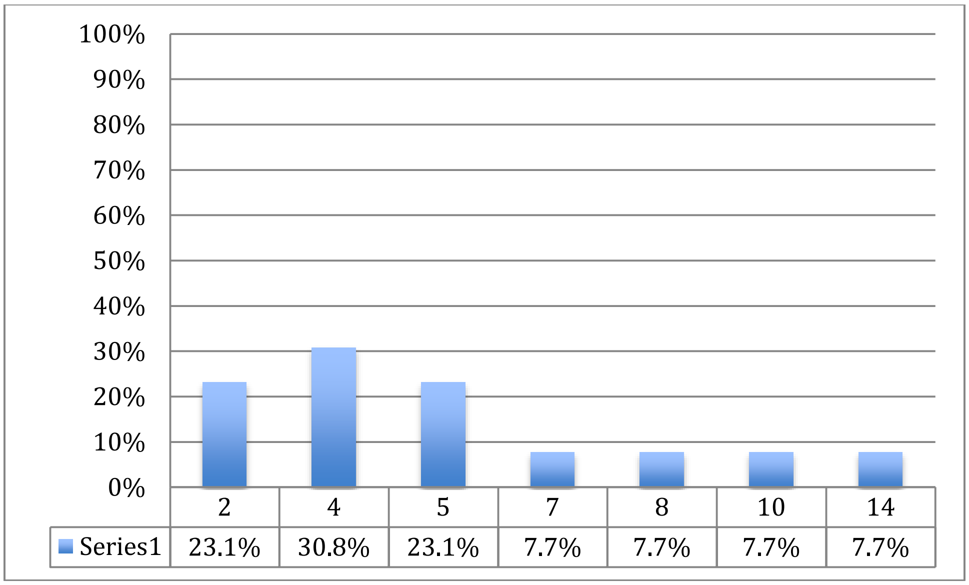
For three schools (Coast Guard Academy, Naval Academy, Southern Methodist University), the goal of RT-19A product development was to develop functional prototypes. At Stevens, the PI stated that while last year's prototypes were conceptual in nature, students would focus this year's efforts on "data acquisition and model validation." Student teams at three schools worked on development of two or more different prototypes. At Smith College and University of Hawaii Manoa, students worked on subsystems development with their partner schools.

Auburn University	Portable UVA to be launched by soldier to reconnoiter hostile environment by air
Air Force Academy	A. Small scale, low voltage, battery management and charging system B. Small scale model of the power plant and vehicle providing proof of concept
Coast Guard Academy	A. Shipboard wastewater treatment system development for Coast Guard cutters (includes development of membrane-bioreactor for treating shipboard gray water and pollutant removal) B. Natural gas engine conversion C. Autonomous sailing vessels
Connecticut College	Small sailing robots that can operate autonomously in navigation and communicate with each other for coordinated operations
Military Academy	Cockpit/Crew Station of the Future (2035) used as a simulator to train pilots.
Missouri University of Science and Technology	Immersive training vests with position reporting and vibrators
Naval Academy	Fully functional, independently powered (e.g. renewable power source) water purification system capable of supporting at least 80 people from multiple water sources
Smith College	Water purification system – specifically, power sub-system in partnership with Naval Academy
Southern Methodist University	Interactive, immersive training environment with human gesture tracking and facial emotion capture
Stevens Institute of Technology	Prepositioned Expeditionary Assistance Kit/Green Housing
Sweet Briar College	Immersive technology to alleviate phantom limb pain
University of Hawaii at Manoa	Distributed systems assurance processes and methods in partnership with Southern Methodist University
University of Virginia	A. Sample (field tested) water sampling kit for the Army B. Phantom limb pain reduction system.

Team Size

PIs reported that team sizes ranged from 2 -14, with a median number of 7 students per team. The average team size was 6 students per team. The highest percentage of PIs, 30.8%, reported having 4 students per team.

All institutions - By number of students per team



About one-quarter (23.1%) of PIs reported that students had no experience working in multidisciplinary teams.

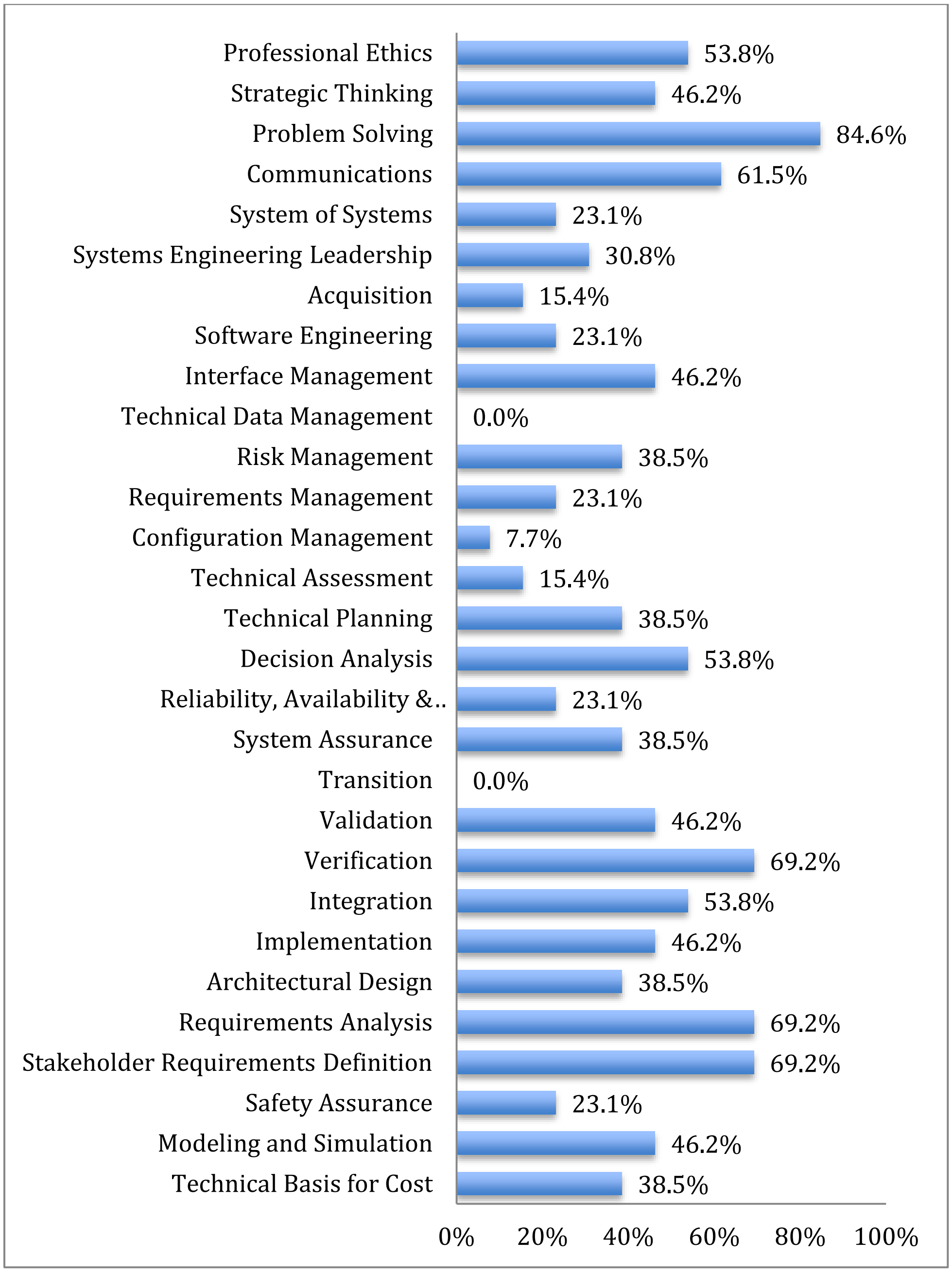
Definition of Systems Engineering

Three schools (Naval Academy, Stevens, University of Virginia) use the standard INCOSE definition when explaining systems engineering to their students. Four schools (Air Force Academy, Coast Guard Academy, Military Academy, Missouri University of Science and Technology) use their own definitions, typically focusing on lifecycle activities of requirements, design and prototyping. Auburn exposes students to several definitions, including the one offered by Charles Wasson in his textbook: "Systems engineering is the multidisciplinary application of analytical, mathematical, and scientific principles for formulating, selecting, and developing a solution that has acceptable risk, satisfies user operational needs, and minimizes development and lifecycle costs while balancing stakeholder needs."

Three schools (Smith, Southern Methodist, Sweet Briar) provide no definition of systems engineering to their students in their first course. At Smith and Southern Methodist, they prefer to let the students develop their own understanding of systems engineering after mastering some of the specific skills that they practice on their projects. Sweet Briar does not have a systems engineering curriculum, so students discover their own definitions as their interests dictate.

Competencies Addressed

Faculty at all thirteen schools answered the survey question on SPRDE-SE/PSE systems engineering competencies and course foci. Problem Solving (84.6%), Requirements Analysis (69.2%), Stakeholder Requirements Definition (69.2%), Validation (69.2%), and Communications (61.5%) were listed as course foci by the highest percentage of faculty.



Dissemination

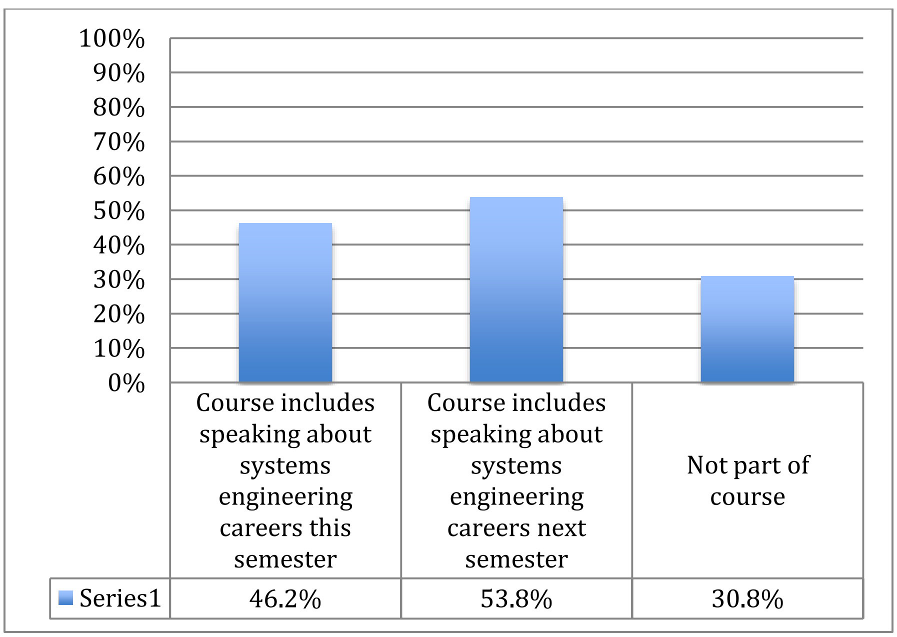
Four schools (Stevens, Sweet Briar, University of Virginia, Military Academy) plan on student participation at conferences and competitions. Students from Stevens will compete at the annual West Point competition and will present at NDIA (National Defense Industrial Association). Sweet Briar students will present at SIEDS (Systems and Information Engineering Design Symposium). University of Virginia students will present at SIEDS and compete at West Point. The Military Academy students will compete at West Point and at the Boeing Design Competition between Army, Navy, and Air Force.

Three schools have submitted papers to conferences so far. Missouri University of Science and Technology and Stevens have submitted papers to ASEE (American Society of Engineering Education). Naval Postgraduate School has submitted a paper to ASNE (American Society of Navy Engineers).

Faculty Reports of Career Awareness Education

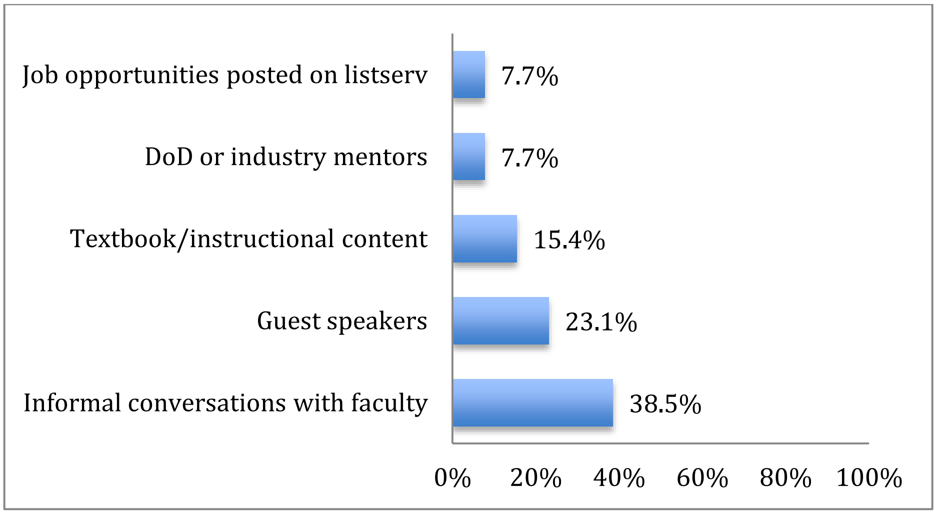
Only four of the 13 schools reported that they had not, and did not intend to, include discussing systems engineering career opportunities as part of the course:

All institutions - By SE career inclusion



But all schools expected that their students would learn about systems engineering careers in a variety of other ways, with informal conversations between students and faculty at the top of the list:

All institutions – By methods of career awareness education



Mentorships

The following section on RT-19A mentors includes data pertaining to:

- DoD mentors and their roles
- Type and frequency of DoD mentor communication
- Industry mentors and their roles
- Type and frequency of industry mentor communication
- External faculty mentors

DoD Mentors

Nine of thirteen schools reported that they had secured a DoD mentor. Below is a table with the names of the mentors and their affiliation. One university (Auburn) and three of the four partner schools did not have mentors, although one partner school (Smith) expressed the desire for one.

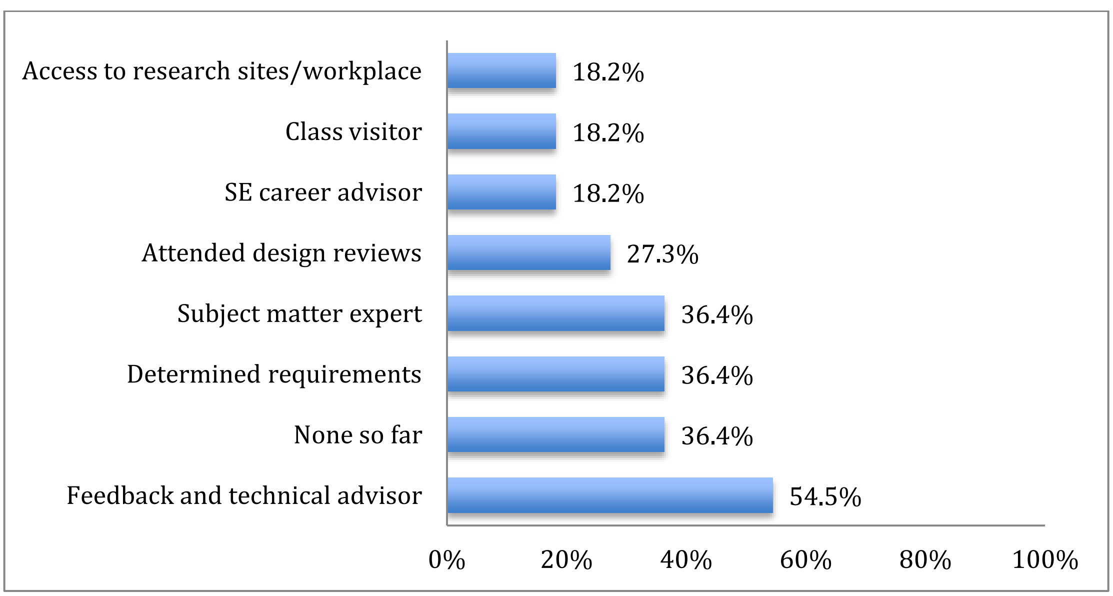
Mentors were selected for a variety of reasons, including personal interest in the students' projects and/or the chosen problem area (for example, CDR Kim Watkins' interest in the immersive technologies being developed at Southern Methodist University). At two institutions (Military Academy, University of Virginia), the mentors had also mentored RT-19 students.

University	Mentor name	Organization
Auburn University	None	
Air Force Academy	Colonel Brett Lloyd	USAF Reserve
Coast Guard Academy	Major Georges Dosso & several other researchers	USCG R&D center
Connecticut College	None	
Military Academy	Bill Crawford Paul DiNardo David Jacques	AMRDEC AMRDEC AFIT

Missouri University of Science and Technology	Paul Barnes Robert Mantz	Army Research Laboratory
Naval Academy	CDR Kim Watkins CDR G.P. Sandhoo	US Marine Corps Training & Education Command/ DISA/OSD-ASD (R&E)
Smith College	None	
Southern Methodist University	Michael Woodman Kendy Vierling CDR Kim Watkins	Human Performance, Training, & Education, MAGTF Training Simulations Division US Marine Corps Training & Education Command/DISA
Stevens Institute of Technology	Jack L. Price, Ph.D.	Director of Research NSWC Carderock Division
Sweet Briar College	Yes, unnamed	
University of Hawaii at Manoa	None	
University of Virginia	Colonel Nancy Grandy Phil Stockdale Bill Campbell	 Office of Naval Research Navy Ordnance (NAVSEA)

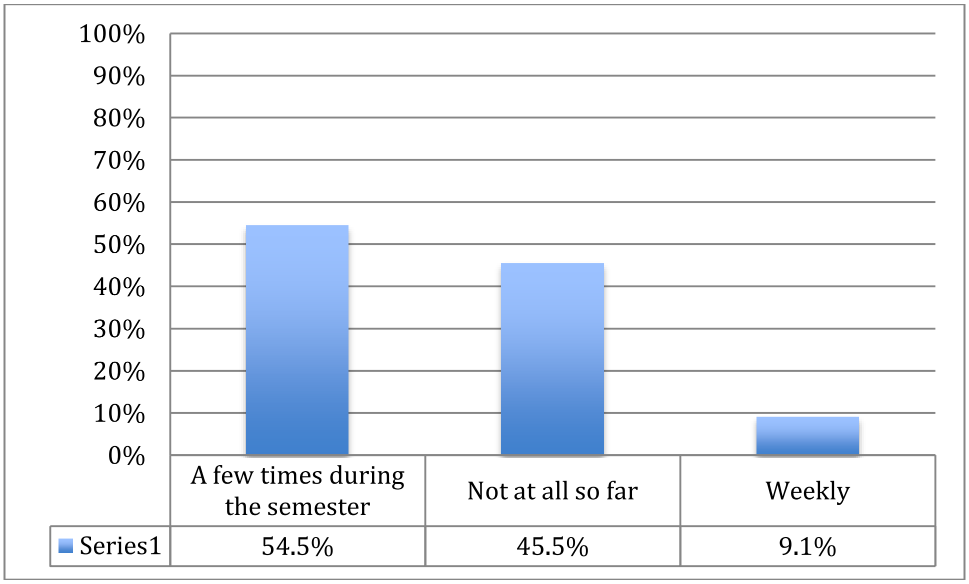
As of January 2012, mentors at four military institutions (Air Force Academy, Coast Guard Academy, Military Academy, and Naval Academy) had not yet played an active role in RT-19A. Below is a chart of the DoD mentors' roles at each institution, with mentors acting in one or more possible roles.

All institutions – By DoD mentor role



At schools with active DoD mentors, most communicated several times during the semester:

All institutions - By frequency of communication with DOD mentor



Email, telephone, teleconference, videoconference, and physical visits were common forms of interaction at schools with active DoD mentors.

University	Type of DoD mentor communication
Auburn University	N/A[6]
Air Force Academy	Email
Coast Guard Academy	Weekly telephone and email exchange. Served as client, subject matter expert. Helped to determine requirements, gave feedback and technical advice, provided equipment support and attended design reviews. Mentor visited campus and students visited mentor at worksite.
Connecticut College	N/A
Military Academy	None so far
Missouri University of Science and Technology	Email a few times during the semester
Naval Academy	None so far
Smith College	N/A
Southern Methodist University	Email, teleconference, videoconference a few times a semester. Shared workspace. Intensive communication between faculty, mentor and students at beginning of semester during acquisition stage. Served as client and subject matter expert, helped determine requirements, gave feedback & technical advice, attended

[6] N/A – refers to schools without DoD mentors

	design reviews, provided access to workplace and discussed SE careers. Mentor visited campus.
Stevens Institute of Technology	Once during critical design review by teleconference/ videoconference. Gave feedback and technical advice.
Sweet Briar College	Students visited mentor off campus a few times during fall semester. Served as client and subject matter expert, helped determine requirements, gave feedback & technical advice.
University of Hawaii at Manoa	N/A
University of Virginia	Communication via email, teleconference, videoconference a few times a semester. Served as client and subject matter expert, helped determine requirements, gave feedback and technical advice, attended design reviews. Mentors visited campus and students visited the mentor off campus.

Industry Mentors

11 of the 13 PIs reported that they had industry mentors who assisted student teams and faculty as systems engineering consultants or technical advisors on institution-specific technologies and research areas, including wind turbine technology (Coast Guard Academy), software systems assurance consultation (University of Hawaii Manoa), or disaster relief (Stevens Institute). Most communicated by email, teleconference, or telephone. Several mentors visited students on campus and attended design reviews. Similar to the DoD mentors, industry mentor roles, frequency and type of communication varied from school to school. At three institutions (MUST, SMU, UVA), the industry mentors carried over from RT-19. Two of the four partner schools did not have industry mentors.

University	**Industry mentor**	**Company**	**Area of expertise**
Auburn University	Advisory board[7]	NASA, Missile Defense Agency, US Army Aviation and Missile Command, Auburn University Huntsville Research Center, Frontier Technology[8]	Systems engineering
Air Force Academy	Engineers	American Electric Vehicles	Electrical engineering

[7] Auburn University's Advisory Board as reported to CSSE - ISNY on October 2011 included: Tom Channell (US Army Aviation and Missile Command), Ms. Patricia Gore, (Missile Defense Agency), Lavan Jordan (Frontier Technology), John Olson (NASA Headquarters Office), and Rodney L. Robertson (AU Huntsville Research Center).

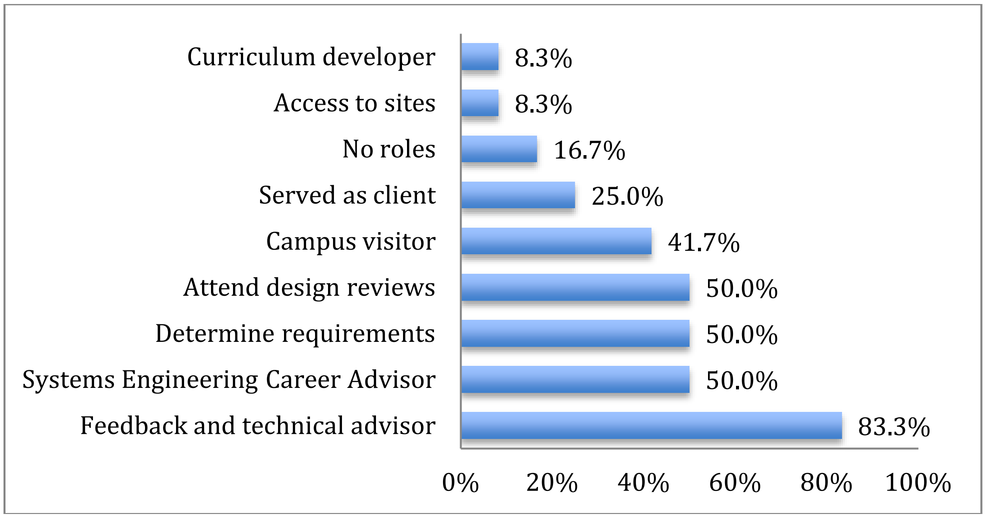
[8] PI listed these as industry mentors, not DoD mentors.

Coast Guard Academy	Ken Kennedy	Retired, Hamilton Sundstrand	Turbine expert
Connecticut College	None		
Military Academy	Ed Winkler	The Boeing Company	Systems engineering
Missouri University of Science and Technology	Lou Pape Dale Waldo Al Brown Bob Scheurer Nancy Pendleton Rob Simons Michael K. McClelland Niel Whipple	The Boeing Company	Systems engineering
Naval Academy	Greg Hanswon	Aqua Sun	Water purification technology
Smith College	None		
Southern Methodist University	Pete Muller Michael F. Siok, Tim Woods	Potomac Training Corporation Lockheed Martin Aeronautics Company	Immersive training environments defense contracted system development and analysis
Stevens Institute of Technology	Tom Newby George Isabella	Buro Happold Engineers BAE Systems, NJ	Disaster relief Systems testing & protocols
Sweet Briar College	Panel of engineers	Northrup- Grumman	SE & communication systems
University of Hawaii at Manoa	Joel Wilf Dr. Allen Nikora	NASA Jet Propulsion Laboratory's Process and Product Quality Assurance group (5124) and Assurance Research group[9]	Software intensive systems assurance
University of Virginia	Engineers	Northrup- Grumman	SE & communication systems

Two institutions (Air Force Academy and MUST) reported no interaction with their industry mentors to date. The rest of the industry mentors acted as technical advisors. Half also helped determine requirements, attended design reviews, and gave students career advice. In the chart below, mentors could play one or more possible roles:

[9] PI listed these as industry mentors, not DoD mentors.

All institutions – By industry mentor role (n=12)[10]



Similar to the DoD mentors, the industry mentors communicated with students primarily through email, telephone, campus visits, and attendance at design reviews.

University	Type of Industry mentor communication
Auburn University	On campus few times during the semester. Gave feedback and technical advice, presented in class and discussed SE careers.
Air Force Academy	None so far, but industry mentors will visit in the spring.
Coast Guard Academy	Weekly telephone and email exchange. Served as subject matter expert. Gave feedback and technical advice, provided access to workplace and attended design reviews.
Connecticut College	N/A
Military Academy	Biweekly communication with telephone, email, teleconference, and a campus visit. Served as subject matter expert, helped determine requirements, gave feedback and technical advice, equipment support, and attended design reviews.
Missouri University of Science and Technology	Weekly communication by email, telephone and teleconference and shared online portal. Served as client, helped determine requirements, gave feedback and technical advice, and attended design reviews, and discussed systems engineering careers.
Naval Academy	Email and telephone communication a few times a semester. Served as subject matter expert, helped determine requirements, gave feedback and technical advice, and provided equipment support.
Smith College	N/A
Southern Methodist University	Communicated with students a few times during the semester on email, videoconference, and campus visit. Served as subject matter expert, gave feedback and technical advice, and discussed SE

[10] One PI did not answer this question.

	careers.
Stevens Institute of Technology	Communicated with students a few times a semester by email and visited campus. Served as subject matter expert, helped determine requirements, attended design reviews, gave feedback and technical advice, and discussed SE careers.
Sweet Briar College	Students visited off-campus a few times a semester. Served as client and subject matter expert. Gave feedback and technical advice, attended design reviews, and discussed SE careers.
University of Hawaii at Manoa	Communicated a few times during the semester by email, telephone and through a shared online portal. Served as subject matter expert, helped determine requirements, gave feedback and technical advice, and discussed SE careers
University of Virginia	Communicated via telephone and teleconference a few times a semester and campus visit. Students visited mentor off campus. Helped determine requirements, gave feedback and technical advice, and attended design reviews.

External Faculty Mentors

In addition to the DoD and industry mentors, at some universities, discipline-specific advisors also worked with teams and individual students. Below is a table of institutions with external faculty members who advised student capstone projects but were not the students' primary team advisors, course instructors, or capstone coordinators.

University	External mentor	Area of expertise
Auburn University	Unnamed faculty member	Automotive engineering
Air Force Academy	No	
Coast Guard Academy	Mec Eng Section Chief Dr. Andy Foley	Mechanical engineering, gas turbine technology, biodiesel
Connecticut College	No	
Military Academy	Yes, all	Discipline-specific
Missouri University of Science and Technology	No	
Naval Academy	Various Military, Ocean, Mechanical, and Electrical engineering faculty	Discipline-specific
Smith College	No	
Southern Methodist University	No	
Stevens Institute of Technology	External department advisors	Discipline-specific
Sweet Briar College	No	
University of Hawaii at Manoa	No	
University of Virginia	No	

Overall, industry mentors communicated with more frequency than DoD mentors, perhaps because of their proximity to schools or their existing relationships with faculty.

Areas of Success

The PIs reported that the RT-19A project was successful with their students for a number of reasons, some of which were common to many institutions and some particular to only one or two:

Communication with clients and mentors	Air Force Academy Coast Guard Academy Military Academy Missouri University of Science and Technology Southern Methodist University University of Virginia
Interest in real-life problem	Auburn University Naval Academy Smith College Sweet Briar College University of Virginia University of Hawaii Manoa
Grasp of SE content knowledge	Air Force Academy Missouri University of Science & Technology Southern Methodist University Smith College University of Hawaii Manoa
Weekly debriefing and planning meetings between PIs and/or teaching assistants	Auburn University Missouri University of Science & Technology University of Virginia
Faculty technical and teaching experience carried over from last year's project	Stevens Institute of Technology University of Virginia
Collaboration between student teams (teams include capstone teams, internal university collaborations & partner institutions)	Coast Guard Academy Southern Methodist University University of Virginia
Utilization of subject matter expertise	Sweet Briar College University of Virginia
Work with a faculty member from another discipline	University of Virginia
Solicitation of RT-19A students	University of Hawaii Manoa
Student team organization	Naval Academy
Communication between PIs/ graduate student advisors to students	Military Academy
Assignment of Systems Engineering PhD students as project managers	Military Academy
Increased professional and academic networking opportunities	Connecticut College

Communication and collaboration were two interrelated areas of success cited on multiple levels, including the interaction of PIs with one another, PI interaction with students, and student interaction with mentors.

At Auburn, “weekly meetings between PIs and teaching assistants to review progress, discuss ideas for improvement, and coordinate effort…kept the course on track, allowed problems to be addressed early, and gave everyone the opportunity to contribute meaningfully and visibly.” According to the PI from the University of Virginia, complementary expertise between faculty members, e.g. [multiple] “perspectives to the students and two styles … as regards handling team dynamics, progress, etc.” facilitated planning, student advising and instruction. One PI (SMU) reported on the benefits of internal university collaboration between RT-19A senior capstone design students working on rapid prototyping and students in another program called Skunkworks Immersion Design Experience. The interaction between the two groups produced “a very good integration of system design and early development lifecycle risk mitigation.” At another institution, WebEx calls with DoD and industry mentors (MUST) were well-received by students.

Five PIs reported that student interaction with mentors was an area of success. Students gave presentations for key stakeholders (Military Academy) and met face-to-face with DoD/industry mentors (Air Force Academy, Southern Methodist University, University of Virginia). They “appreciated getting feedback from a wide variety of systems and defense professionals” (University of Virginia).

Five PIs also cited student interest as an area of success. Students were motivated to build a working prototype (Auburn University, Connecticut University) and connect to researchers and teams at partner schools (Connecticut College, Southern Methodist University, University of Virginia). Students “immensely enjoyed working on the projects because they were “wonderfully challenging, real-world” problems (Sweet Briar, University of Hawaii Manoa) and “structured so that they progressed like a real project” (University of Virginia). Student also liked the “puzzle” dimension of building sub-systems (Smith College) and directly applying their engineering knowledge to develop products that “moved” (Air Force Academy) or “flew” (Auburn University). The PI at Stevens Institute of Technology reported that students were motivated to research issues on sustainability and disaster relief.

The PIs also described how students successfully engaged with various systems engineering competencies, including Requirements Analysis, Systems Integration, Systems Assurance, Documentation, often with partner schools in a remote capacity (Smith College, Southern Methodist University, University of Hawaii Manoa, University of Virginia). At Coast Guard Academy, cadets learned “the experience (both positive and frustrating) of working with real customers with differing expectations.” PIs also experienced success in teaching students about the need for well-written documentation (Air Force Academy).

Other areas of success reported by PIs included recruiting PhD students as team managers (Missouri University of Science & Technology), breaking student capstone groups into interdependent sub-teams working on subsystems (Naval Academy), utilizing PI’s subject matter expertise (Sweet Briar College, University of Virginia) and introducing students to the systems engineering professional world via conferences and meetings (Connecticut College).

Areas of Challenge

The PIs also reported a number of challenges, some of which were again common to many institutions and some particular to only one or two:

Systems Engineering concepts & content knowledge	Auburn University Naval Academy Southern Methodist University Smith College Stevens Institute of Technology University of Virginia
Communication between team members from separate engineering disciplines or partner institutions	Auburn University Smith College Sweet Briar College University of Hawaii Manoa University of Virginia
Team diversity and composition	Auburn University Naval Academy Sweet Briar College
Space for large-scale prototype design/meetings	Coast Guard Academy Naval Academy University of Virginia
Alignment of course materials/lectures with project design or with multidisciplinary student	Naval Academy Southern Methodist University
Restrictions on communication with government mentors or military schools	Smith College Southern Methodist University
Funding delays/subcontracting	Connecticut College University of Hawaii Manoa
Communication between students & faculty on technical problems	University of Virginia
Communication between engineering departments	Military Academy
Alignment of grading across departments	Southern Methodist University
Time constraints	Missouri University of Science & Technology

Students also experienced challenges in grasping certain systems engineering concepts and their technical/analytic applications. At Smith, students struggled with "open-ended problems" and the lack of a specific client. At Naval Academy, the modeling and analysis phase of concept development was difficult because abstract problem-solving skills were demanded of the students:

> "[Each] sub-team had its own unique set of modeling and analysis activities to develop, so they were less able to "cookie-cutter" follow the examples in class. This might be mitigated in the future by allotting more time in class for this part of the project."

At the University of Virginia, students had "difficulty making final concept of operations." PIs recommended regular meetings and communication between teams and faculty to identify

problems in the early stages of development. Other students struggled with the "technical jargon [of other disciplines]… functional flows and hierarchical decisions" (Auburn University). Students also experienced technical challenges integrating various parts of complex systems, but such challenges were "to be expected" (Southern Methodist University).

Communication was also cited as an area of challenge as well as an area of success, although for several PIs noted that this was a good thing, For instance, one wrote that the difficulty of discussing work across disciplinary boundaries was "good practice for the students in working in the real world" (Sweet Briar). At Auburn University, the PI noted that small problem-solving activities rooted in Challenge-Based Learning pedagogy helped students to improve their day-to-day communication and overall teamwork skills.

The implementation of various interactive communication technologies also proved a challenge. The PI from University of Virginia reported using multiple types of interactive communications technologies, including Skype and Oovoo, but with little success. Although teleconferencing proved to be the most expedient solution, they wanted to use videoconferencing and planned on doing so in the upcoming semester. One PI reported that students encountered some problems in the exchange of digital documents with DoD/USMC clients because of government restrictions limiting clients' access to Dropbox. A file-sharing alternative was GoogleDocs, but "it only supports a limited number of file formats which may not be sufficient to support all project artifacts deliverables" (Southern Methodist University). Smith College students also experienced difficulty with distance communication because of Naval Academy's Skype restrictions.

Team diversity and interdisciplinary communication were challenges noted by several institutions. At Sweet Briar College, "teams needed to have more diverse majors." One PI suggested that active, cross-disciplinary recruitment of teams and the reduction of "individual assignments in favor of more team assignments" would help build stronger teams and shared content knowledge (Auburn University). Another PI said that interdisciplinary, assigned teams were difficult but gave students real-world exposure to systems engineering work:

> "As with almost any real-world project, especially one in which teams are assigned rather than chosen, there have been interpersonal issues between some of the students, where they either don't get along or agree with another's approach. However, this has turned out to be a realistic and valuable learning experience, and I don't plan to take active steps to avoid it in the future." (Naval Academy)

Another shared challenge for faculty was mapping SE topics and lectures to capstone design work, and teaching a varied group of students with different existing systems engineering and disciplinary knowledge (Naval Academy and Southern Methodist University). One PI suggested extra time was needed for planning a course of such complexity and that it helped to motivate capstone instructors if the DoD problem area was aligned with their research interests (Southern Methodist University).

Other PIs reported issues common to project management, including funding, time constraints, and having adequate space for prototype design or large group meetings. Three partner institutions reported funding delays and problems with subcontracting with the main RT-19A institution (Connecticut College, University Rhode Island, and University of Hawaii Manoa).

ANALYSIS OF STUDENT PARTICIPANTS

This section will provide an overview of the demographic characteristics of the students engaged in the RT-19A capstone courses, based on an analysis of the student pre-surveys from the thirteen schools that submitted them. Those that did not respond to the survey are highlighted in gray:

RT-19A Main Institution	**Partner Institution**
Air Force Academy	
Auburn University	Tuskegee University
Coast Guard Academy	Connecticut College
	University of Rhode Island
Missouri University of Science & Technology	
Military Academy	
Naval Academy	Smith College
Naval Postgraduate School	
Southern Methodist University	University of Hawaii Manoa
Stevens Institute of Technology	
University of Virginia	Sweet Briar College

Students at two institutions, Connecticut College and University of Rhode Island, have not yet begun their capstone partnership so there is no student data from them. There were no student participants at Auburn's partner institution, Tuskegee University. Students from NPS did return surveys, but the PI did not, so their data cannot be matched with the PI's report.

The following section on RT-19A students includes data on:

- Survey participation rate
- Academic status and class year
- Major
- Gender and Ethnicity
- Experience with general engineering
- Experience with systems engineering
- Systems engineering career interest

Survey Participation Rate

A total of 285 students returned surveys. While the total number of students enrolled in capstone courses according to the PI report was only one higher than the number of students returning surveys, a closer look shows differences at the institutional level.

In two cases, the difference can be attributed to greater student response in the survey than in the PI's report because more students were taking the course than were working on a DoD problem area. For one (NPS), the PI did not respond to the interim survey at all. In five cases, the PI total was much higher than the number of surveys returned. For example, according to the SMU PI, 46 students were enrolled in the Senior Systems Engineering Capstone but only 8 were working on the DoD problem area. Where there are particularly large discrepancies, the higher number is highlighted in gray:

	Surveys	PI Total
Air Force Academy	31	5
Auburn University	31	29
Coast Guard Academy	26	42
Military Academy (West Point)	4	4
MUST	19	48
Naval Academy	28	38
Naval Postgraduate School	89	0
Smith College	4	4
Southern Methodist University	8	46
Stevens Institute of Technology	20	24
Sweet Briar College	4	4
University of Hawaii at Manoa	4	24
University of Virginia	17	18
Total	285	286

Academic Status and Class Year

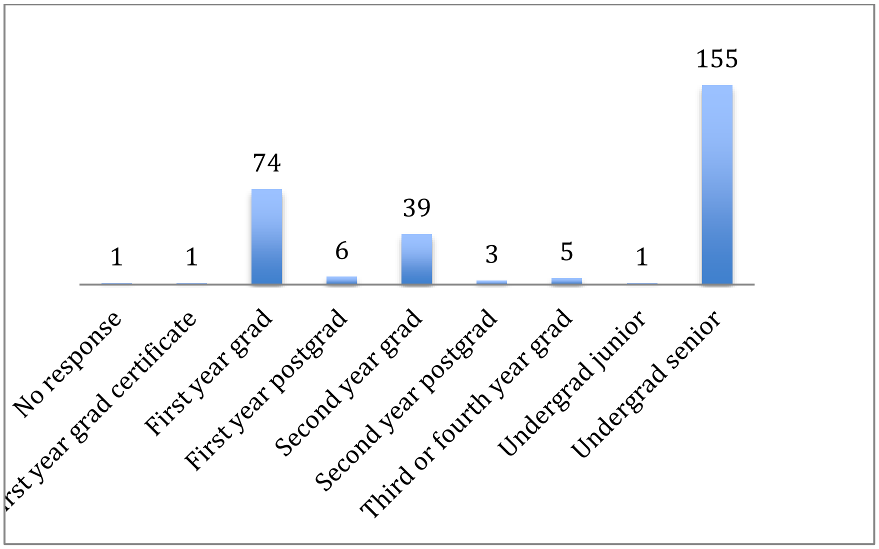
Of the 285, 156 were undergraduates, 110 were graduate students (89 from NPS), and 19 were postgraduates:

	Frequency	Percent
Graduate	110	38.6
Postgraduate	19	6.7
Undergraduate	156	54.7
Total	285	100.0

While last year several institutions had mixed undergraduates and graduates in a single class, this year students from only one institution (Auburn) reported a mix—in this case, a class of 31 that was one-third (32.3%) undergraduates and two-thirds (67.7%) graduate students. The NPS and MUST respondents were entirely graduate students and post-graduates, while respondents from the remaining ten institutions were entirely undergraduates.

Most of the undergraduate respondents were seniors, while most of the graduate students were in their first or second year. The chart and tables below show class status for all institutions and by individual institution:

All Institutions - By Class year
(n=285)



	Frequency	Percent
No response	1	.4
First Year Graduate Certification program	1	.4
First year graduate student	74	26.0
First year postgraduate student	6	2.1
Second year graduate student	39	13.7
Second year postgraduate student	3	1.1
Third or fourth year graduate student	5	1.8
Undergraduate Junior	1	.4
Undergraduate Senior	155	54.4
Total	285	100.0

	STATUS			Total
	Grad	Postgrad	Undergrad	
Air Force Academy	0	0	31	31
Auburn University	21	0	10	31
Coast Guard Academy	0	0	26	26
Military Academy	0	0	4	4
MUST	18	1	0	19
Naval Academy	0	0	28	28
Naval Postgraduate School	71	18	0	89
Smith College	0	0	4	4
Southern Methodist University	0	0	8	8
Stevens Institute of Technology	0	0	20	20
Sweet Briar College	0	0	4	4
University of Hawaii at Manoa	0	0	4	4
University of Virginia	0	0	17	17
	110	19	156	285

Class Size

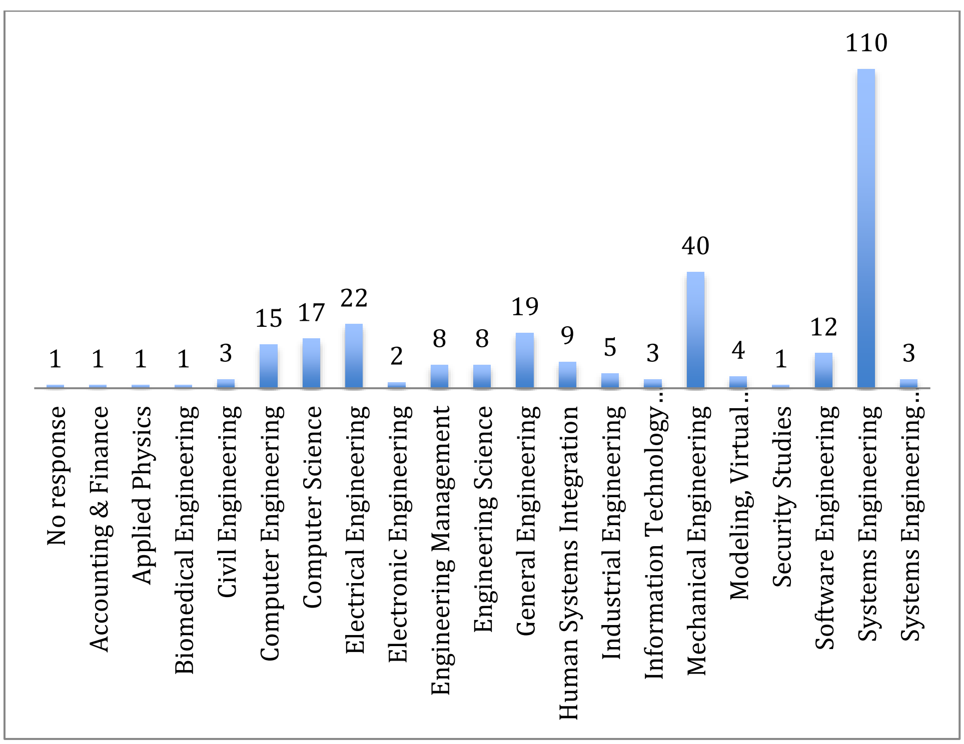
Class size as reported by the students ranged from a low of 4 (MA, SBC, Smith, University of Hawaii Manoa) to a high of 89 (NPS). The average class size was 22 (median = 19, mode = 4, SD = 23).

Major

Students in 10 of the 13 institutions were from two or more engineering disciplines. Students at one institution (NPS) came from nine different majors, with various engineering disciplines, including Electrical, Electronic, Mechanical and Systems Engineering represented, as well as related fields such as applied physics and security studies. Student respondents at three institutions came from only one engineering discipline, either Mechanical Engineering (CGA) or Engineering Science (Smith College and Sweet Briar College).

The most prevalent major was Systems Engineering, followed by Mechanical and Electrical Engineering. About one-third (38.5%) of those returning surveys were Systems Engineering majors, distributed among 8 of the 13 institutions. Students majoring in Mechanical Engineering were distributed across five institutions while students majoring in Electrical Engineering were distributed across six institutions. Majors represented by only one or two students included Accounting and Finance, Applied Physics, Biomedical Engineering, Security Studies, and, Electronic Engineering.

All Institutions - By major (n = 285)



	Frequency	Percent
No response	1	.4
Accounting and Finance	1	.4
Applied Physics	1	.4
Biomedical Engineering	1	.4
Civil Engineering	3	1.1
Computer Engineering	15	5.3
Computer Science	17	6.0
Electrical Engineering	22	7.7
Electronic Engineering	2	.7
Engineering Management	8	2.8
Engineering Science	8	2.8
General Engineering	19	6.7
Human Systems Integration	9	3.2
Industrial Engineering	5	1.8
Information Technology Management	3	1.1
Mechanical Engineering	40	14.0
Modeling, Virtual Environments and Simulation	4	1.4
Security Studies	1	.4
Software Engineering	12	4.2
Systems Engineering	110	38.6
Systems Engineering Analysis	3	1.1
Total	285	100.0

Gender and Ethnicity

The student population that returned surveys was largely male (80.4%), with only 17.9% female and the rest not reporting gender.

Gender	Frequency	Percent
Male	229	80.4
Female	51	17.9
No response	5	1.8
Total	285	100.0

Two-thirds (66.3%) of the students reported their ethnicity as White, with Asian the second largest grouping:

Ethnicity	Frequency	Percent
White	189	66.3
Asian	39	13.7
Black or African American	25	8.8
Hispanic/Latino	10	3.5
Native Hawaiian or Other Pacific Islander	5	1.8

American Indian/Alaska Native	3	1.1
No response	14	4.9
Total	285	100.0

Experience with Engineering

All but 13 students (4.6%) of the total number of survey respondents (n=285) reported having had engineering experience, either through full-time employment, an internship or co-op, or summer work or a combination of these. However, over one-quarter (28.1%) of students surveyed did not respond to this question, presumably because they also had no experience. Over half of the students who reported that they had had full time work experience came from NPS.

Amount of General Engineering Experience

	Frequency	Percent
Some engineering experience	192	67.4
No engineering experience	13	4.6
No response	80	28.0
Total	285	100.0

Below is a table of students who responded that they had general engineering experience, broken down by type:

Type of General Engineering Experience

	Frequency	Percent
Co-operative education experience or internship	48	25.0
Co-operative education experience or internship & full time employment	3	1.6
Co-operative education experience or internship & work experience during school year	3	1.6
Co-operative education experience or internship & work experience during summer	8	4.2
Co-operative education experience or internship & work experience during summer & full time employment	1	0.5
Co-operative education experience or internship & work experience during summer & work experience during school year	6	3.1
Co-operative education experience or internship & work experience during summer & work experience during school year & full time	2	1.0
Coursework	4	2.1
Full time employment	50	26.0
Work experience during school year	18	9.4
Work experience during school year & full time employment	2	1.0
Work experience during summer	34	17.7
Work experience during summer & full time employment	6	3.1

Work experience during summer & work experience during school year	6	3.1
Work experience during summer & work experience during school year & full time employment	1	0.5
Total	192	100.0

Experience with Systems Engineering

Well over half (58.2%) of the students, from 11 of the 13 institutions, reported having no systems engineering experience. Only 2.1% did not respond to this question.

Systems Engineering Experience

	Frequency	Percent
Some engineering experience	113	39.6
No engineering experience	166	58.2
No response	6	2.1
Total	285	100.0

The largest percentage of those who reported SE experience had gained it through coursework (48.7%), followed by full time employment (19.5%).

Below is a table of students who responded that they had systems engineering experience, broken down by type:

Type of Systems Engineering Experience

	Frequency	Percent
Co-operative education experience or internship	4	3.5
Coursework	55	48.7
Coursework & co-operative education experience or internship	6	5.3
Coursework & co-operative education experience or internship & work experience during summer	5	4.4
Coursework & co-operative education experience or internship & work experience during summer & work experience during school year	1	0.9
Coursework & full-time employment	2	1.8
Coursework & work experience during summer	6	5.3
Coursework & work experience during summer & work experience during school year	2	1.8
Full-time employment	22	19.5
Work experience during school year	2	1.8
Work experience during school year & full-time employment	1	0.9
Work experience during summer	7	6.2
Total	113	100.0

Interest in Systems Engineering Careers

Three-quarters of all students (76.5%) reported moderate to high levels of interest in becoming systems engineers.

General SE Career Interest

	Frequency	Percent
High interest	85	29.8
Above moderate interest	76	26.7
Moderate interest	57	20.0
Below moderate interest	21	7.4
No interest	23	8.1
Don't know/Not sure	18	6.3
No response	5	1.8
Total	285	100.0

Slightly more than two-thirds (69.2%) reported that they had moderate to high interest in working for the government as a systems engineer:

Government SE Career Interest

	Frequency	Percent
High interest	47	16.5
Above moderate interest	80	28.1
Moderate interest	70	24.6
Below moderate interest	25	8.8
No interest	32	11.2
Don't know/Not sure	27	9.5
No response	4	1.4
Total	285	100.0

A somewhat higher percentage (75.1%) reported moderate to high levels of interest in working as a systems engineer for the private sector.

Private Sector SE Career Interest

	Frequency	Percent
High interest	54	18.9
Above moderate interest	86	30.2
Moderate interest	74	26.0
Below moderate interest	17	6.0
No interest	25	8.8
Don't know/Not sure	25	8.8
No response	4	1.4
Total	285	100.0

CONCLUSION

Overall, the student and PI mid-semester responses highlighted the existence of multiple and overlapping capstone course problems areas, prototypes, and systems competencies foci. Surveys described convergent and divergent areas of technical expertise, engineering experience and research interests of faculty, students and mentors involved, perhaps best reflected in the PIs' different approaches to understanding the discipline of systems engineering. When asked to define systems engineering, faculty showed varied pedagogical and epistemological orientations to understanding systems engineering, considering both formal (INCOSE) and informal or experiential definitions of systems engineering (allowing students to construct their understanding of systems engineering through the process of design) as possible pathways to knowledge.

Given these preliminary data, it is hypothesized that the interaction of one or more factors listed below will impact the implementation of capstone courses and affect the outcome of a (successful) student project:

- Early determination of requirements / "fixed requirements"
- Regular consultation and technical advice from DoD/industry mentors
- Several active mentors
- Small team size
- Number of faculty participants
- Number of students with a systems engineering background
- Difficult of problem area chosen
- Ability to complete a prototype and submit to an engineering competition

The final report will analyze student/PI post-surveys and PI interviews with the aim of connecting the development of successful student prototypes to course content, faculty instructional objectives, contributions of external mentors, and student interest in SE careers, DoD problem areas and careers.